ADAPTING FIXED OFFSHORE WIND OR OIL AND GAS DESIGN RULES TO FLOATING OFFSHORE WIND: A COMPLEX CHALLENGE

Quentin Derbanne

INTRODUCTION

HOW TO BENEFIT FROM PAST EXPERIENCE

70 YEARS OF OFFSHORE OIL & GAS PRACTICES AND STANDARDS

API American Petroleum Institute

ISO International Organization for Standardization

IACS International Association of Classification Societies

40 YEARS OF ONSHORE AND FIXED OFFSHORE PRACTICES AND STANDARDS

IEC International Electrotechnical Commission

BUREAU VERITAS 1828

WHERE ARE WE COMING FROM?

LOOK BACKWARD TO MOVE FORWARD

1947
1st offshore fixed platform

1977
1st FPSO

American Petroleum Institute

- API RP 2A (-WSD)
- API RP 2A-LRFD : Fixed Offshore Platforms
- API RP 2FPS : Floating Production Systems
- API RP 2SK : Stationkeeping

International Organization for Standardization

- ISO 19900-1 : General requirements
- ISO 19901-1 : Metocean
- ISO 19902 : Fixed steel offshore structures
- ISO 19901-7 : Stationkeeping systems
- ISO 19904-1 : Floating offshore structure

1890
1st industrial wind turbine in Denmark

1980
1st wind farm of 20 turbines in New Hampshire

1991
1st fixed offshore wind farm in Denmark

2017
1st floating wind farm

International Electrotechnical Commission

- IEC 61400-1 : Wind turbines
- IEC 61400-3(-1) : Fixed offshore wind turbines
- IEC 61400-3-2 : Floating offshore wind turbines

1940 1950 1960 1970 1980 1990 2000 2010 2020

DESIGN METHODS

OIL & GAS	FOWT

Design environmental conditions

OIL & GAS

- 100 years Return Period
- 1,000 or 10,000 years Return Period are sometimes used

FOWT

- 50 years Return Period

Short-term variability is neglected

OIL & GAS

- 3h simulations
- Most Probable Maximum
- Or Mean Maximum
- 30 seeds are usually done

FOWT

- 10 min or 1h simulation
- Mean Maximum
- 6 seeds are required

Safety factors

OIL & GAS

- Various safety factors, mostly empirical

FOWT

- Various safety factors, mostly empirical

WHAT SHOULD BE THE SAFETY LEVEL?

NOTIONAL PROBABILITY OF FAILURE

I OIL & GAS

Large and expensive asset

Important consequences (pollution, production stop)

Manned

$Pf = 10^{-5}$

I 15 MW FOWT

Small and “cheap” asset

Small consequences

Unmanned

$Pf = 5.10^{-4}$


PROBABILITY OF FAILURE
RETURN PERIOD
CHARACTERISTIC RESPONSE
SAFETY FACTORS

01

RETURN PERIOD

RETURN PERIOD

API RP 2A:1969 (1st)

- "Selection of the class to which platforms are designed shall be the prerogative of the owner"
- Both the **25** year and the **100** year RP was common

API RP 2A-WSD:1993 (20th)

- The « **100** year load condition » is recommended: wave, current, wind…

Fixed offshore

API RP 2A:1976 (7th)

- The « **100** year wave » is recommended and becomes the standard practice

API RP 2FPS:2011 (2nd)

- A structural system robustness check is recommended [...] with a return period not less than **1,000** years

Floating offshore

API RP 2FPS:2001 (1st)

- "Not less than a **100** year environment should be considered"

BUREAU VERITAS

RETURN PERIOD

British Standard: BS 6399, 1994	
Basic wind speed	50
Bridges	120
Ultimate limit state	1754
Nuclear installations	10,000

Australian Standard: AS 1170.2-1989	
Serviceability limit state	20
Permissible stress check	50
Ultimate limit state	1,000

Eurocode 1: ENV 1991-2-4:1995	
Reference wind speed	50

Buildings

National Building Code of Canada: NRCC 1990	
Components and cladding	10
Building structural members	30
BuImportant buildings	100

American Society of Civil Engineering: ASCE 7-95	
Unoccupied buildings	25
Normal buildings	50
Important buildings	100

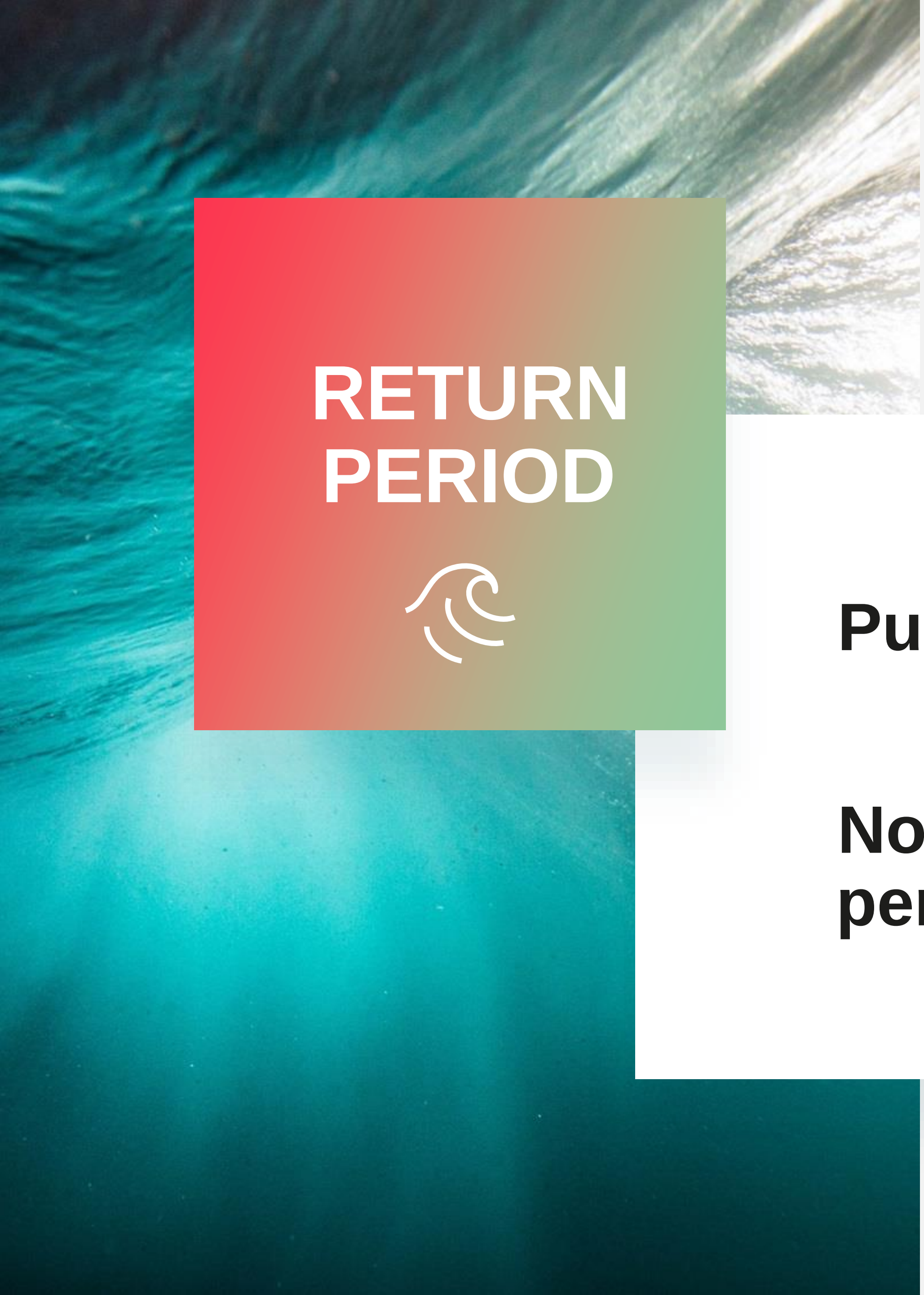
Wind turbines

IEC 61400-1:1994 (1st)	
Extreme wind speed	50

IEC 61400-3:2009 (1st)	
Extreme wind speed	50

IEC 61400-3-2:2019 (1st)	
Extreme wind speed	50

RETURN PERIOD



Pure empiricism

No explicit link between the return period and the probability of failure

02

SHORT-TERM VARIABILITY

SHORT-TERM VARIABILITY

2 PROBLEMS

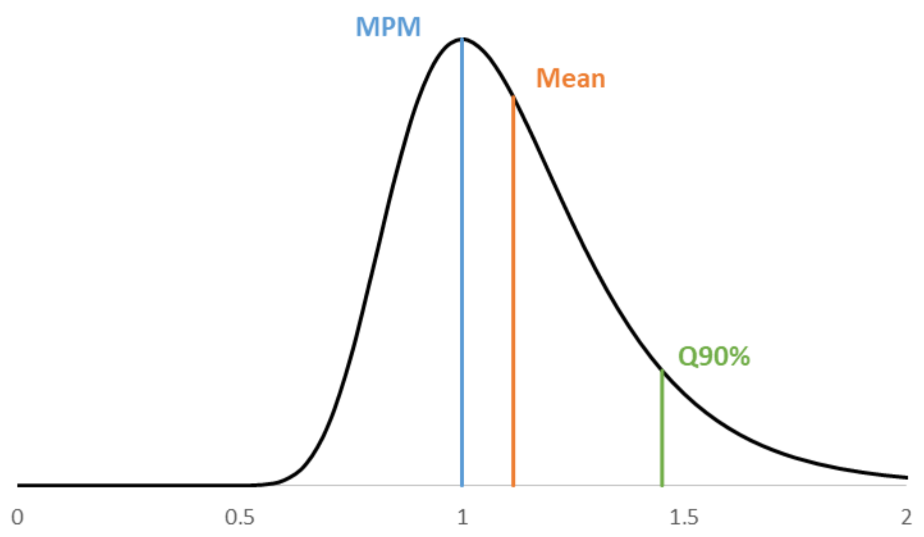
The short-term maximum is a random variable !

- **Variability of the wave loads (sea spectrum)**
- **Variability of the wind loads (wind spectrum)**

1- Which characteristic value to chose ?

2- How to deal with the convergence of the estimator of this characteristic value ?

- **The characteristic maximum is estimated from N simulations only…**



SHORT-TERM VARIABILITY
CHARACTERISTIC VALUE

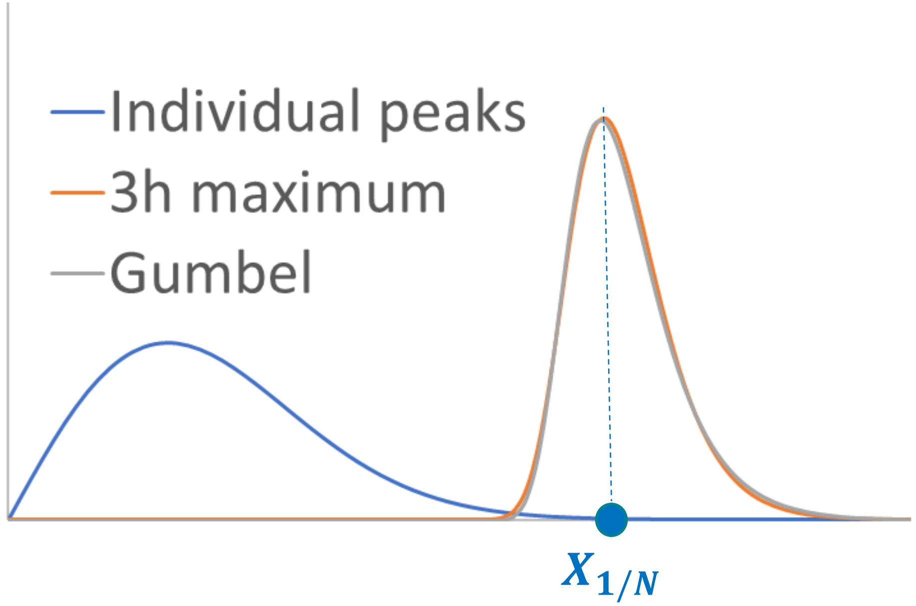
Fixed offshore: no short-term variability

- **Deterministic calculation on “100 year wave”**

Floating offshore

- **Frequency domain computations**
  - individual peaks are Rayleigh distributed
  - “maximum response” is usually defined as the expected maximum
    $$P_{peaks}\left(X_{1/N}\right) = 1 - 1/N$$
  - Maximum 3h response distribution is approximated by a Gumbel distribution
    $$P_{3h}\left(X_{1/N}\right) = (1 - 1/N)^N \approx 37\%$$
    $$P_{3h}(X) = \left(P_{peaks}(X)\right)^N \approx Gumbel(X)$$
  - The Most Probable Maximum of the Gumbel distribution is $\boldsymbol{MPM} = \boldsymbol{X_{1/N}}$

- **Time-domain computations**
  - Most Probable Maximum is used



SHORT-TERM VARIABILITY

CHARACTERISTIC VALUE

Fixed offshore no short-term variability

API RP 2SK:2001 (1st)
- Nothing recommended

API RP 2SK:2005 (3rd)
- expected extreme values
- MPM

ISO 19901-7:2005 (1st)
- MPM

Floating offshore

NORSOK N-003:2007 (2nd)
- **"the variability of the short term extreme value needs to be artificially accounted for"**
  - By multiplying the expected maximum action effect by 1.1 to 1.3
  - or by calculating the action effects at a high fractile value: 85% to 95%

Wind turbines

IEC 61400-1:2005 (3rd)
- When turbulent inflow is used, the mean value […]shall be taken

SHORT-TERM VARIABILITY

CONVERGENCE…

Fixed offshore no short-term variability

API RP 2FPS:2001 (1st)

- Nothing recommended

API RP 2FPS:2011 (2nd)

- "The analysis shall be performed long enough to achieve stationary response statistics"…

Floating offshore

BV NR 493:2004 (1st)

- Correction, depending on the number of seeds: $\hat{\mu} + a\hat{\sigma}$

Number of simulations			
n = 5	n = 10	n = 20	n ≥ 30
0,60	0,30	0,10	0

API RP 2SK:2005 (3rd)

- "The time domain simulation should be long enough to establish stable statistical peak values"
- MPM needs hundreds of simulations
- Or Mean from 5-10 simulations

Wind turbines

IEC 61400-1:2005 (3rd)

- At least six stochastic realizations shall be required

SHORT-TERM VARIABILITY

RESEARCH IS AWARE OF THE PROBLEM

Importance of short-term variability is known for years

- **IFORM contours introduced by Winterstein (1993) neglects this aspect**

Unsatisfactory solutions have been proposed to compute the 100 years response

- **Inflate the Return Period**
  - 200 to 1400 years can be found in the litterature
- **Increase the short-term quantile**
  - 65% to 99.5% can be found in the litterature
- **Apply a correction factor**
  - 1.05 to 1.5 can be found in the littérature

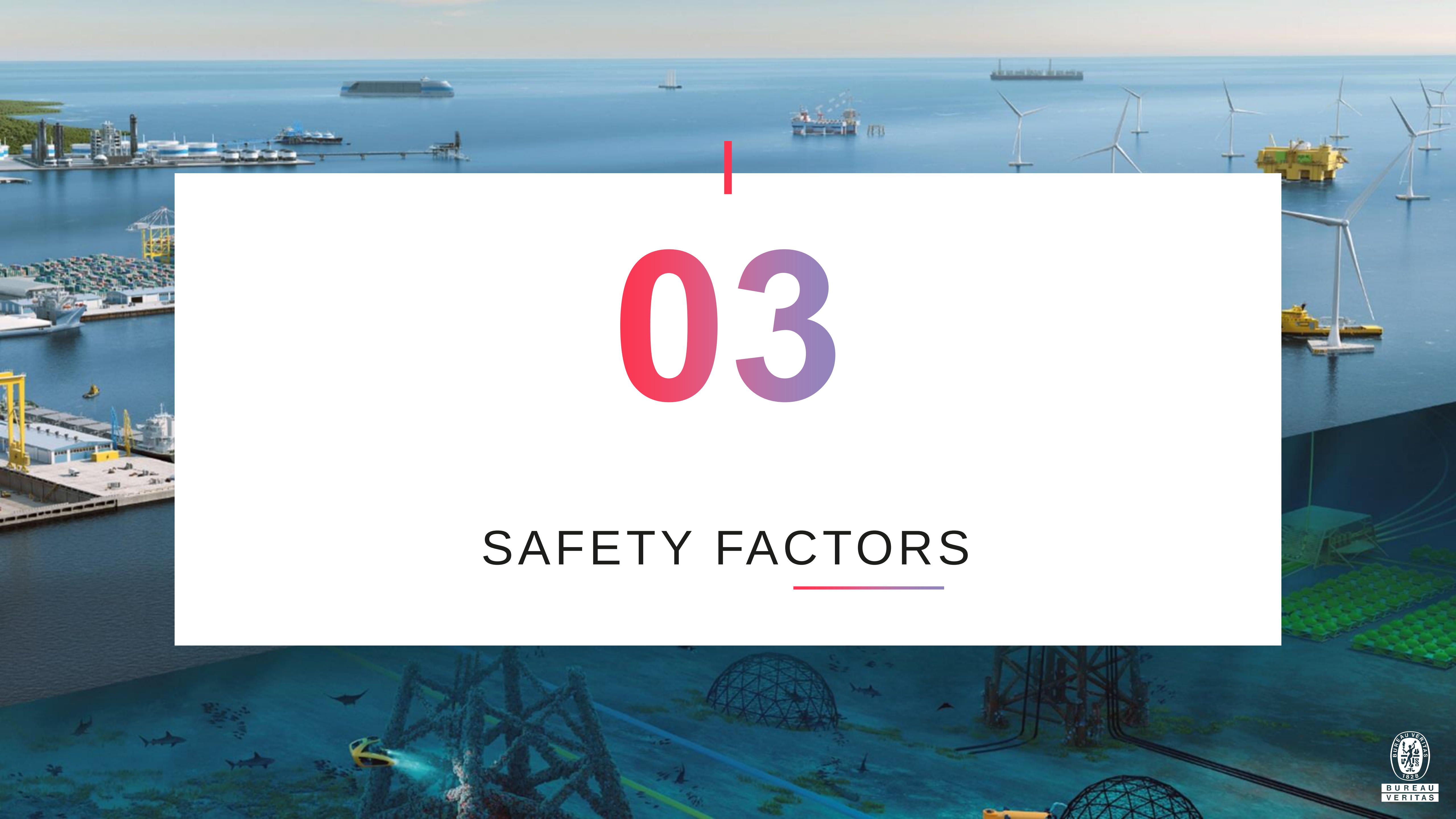
CORRECT VALUES ARE DESIGN DEPENDANT

Nothing useful has been proposed for the convergence

SHORT-TERM VARIABILITY

Choice of the characteristic value not justified

Convergence of the estimator never properly taken into acount



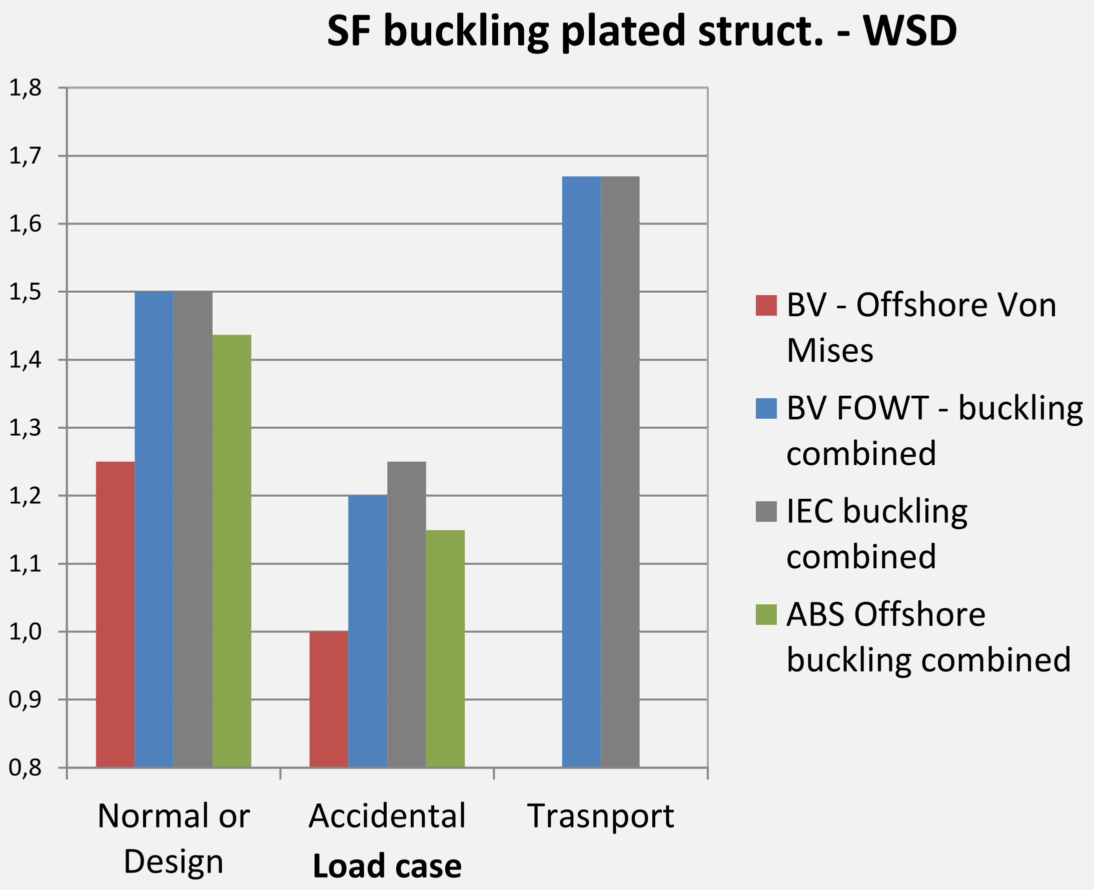
03

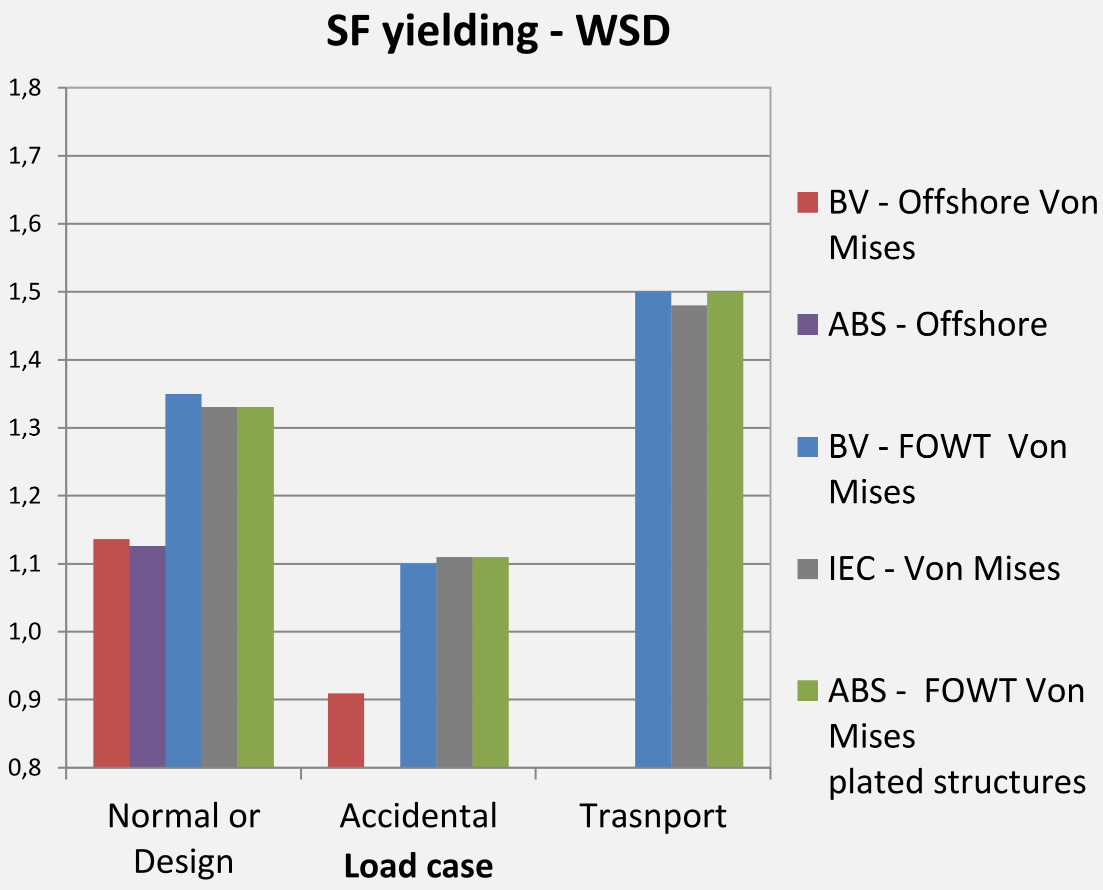
SAFETY FACTORS

BUREAU VERITAS

MANY DIFFERENT SAFETY FACTORS

UNKNOWN OR POOR JUSTIFICATION





MANY DIFFERENT SAFETY FACTORS

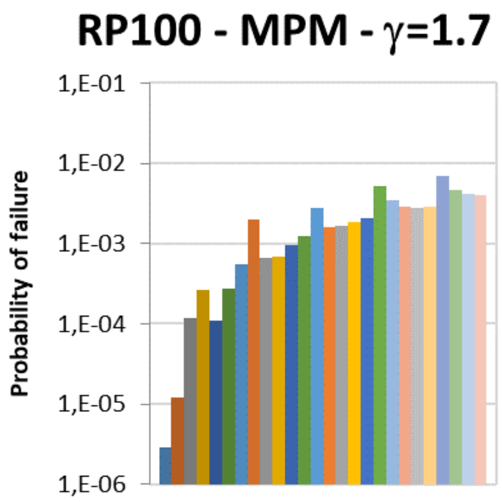
RESEARCH

Many research publications based on reliability analysis…

… giving many different values

Most research work are using the same « design response » definition

- **MPM (or mean)**
- **100 years return period for the environment**



SAFETY FACTORS

Pure empiricism

No explicit link between the safety factors and the probability of failure

A PROPER DESIGN CODE CALIBRATION

BREAK FREE FROM THE PAST

The probability of failure depends on:

- **Aleatory uncertainties**
  - Long-term variability of environmental conditions
  - Short-term variability of the response
- **Epistemic uncertainties**
  - Model uncertainty
  - Limited number of seeds
  - …

The code format should play with:

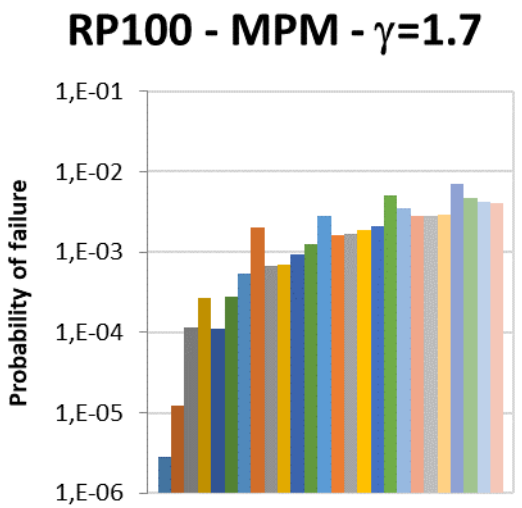
- **The choice of the Return Period for the environment**
- **The choice of the quantile to define the characteristic value**
- **A set of partial safety factors**

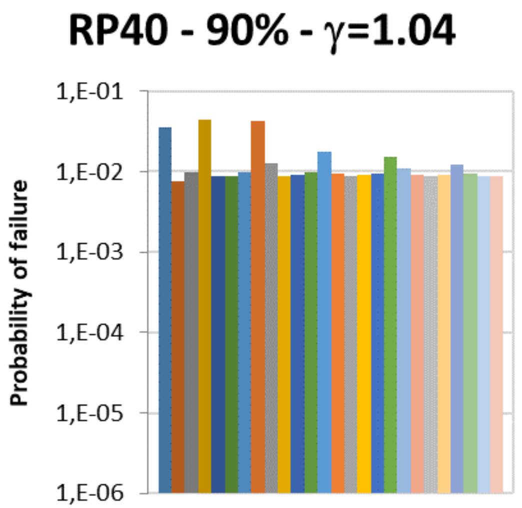
A PROPER DESIGN CODE CALIBRATION

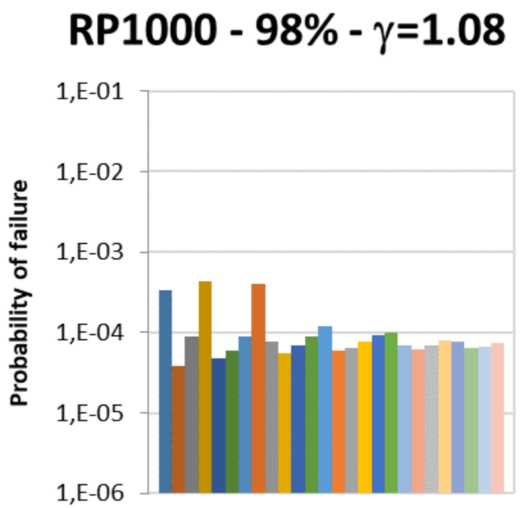
BREAK FREE FROM THE PAST

Example without epistemic uncertainties

P_f	RP	Q	γ	
10^{-2}	40	90%	1.04	Derbanne et al (OMAE 2017)
10^{-4}	1000	98%	1.08	Derbanne (FPSO forum 2017)







CONCLUSION

How to harmonize design rules

CONTINUE AS BEFORE…

- **Empirical choice of Return Period**
- **Keep the Most Probable Maximum**
- **Try to justify the safety factors using reliability analysis**

…OR MOVE FORWARD

- **Empirical choice of a target notional probability of failure**
- **Find the best design code, using reliability analysis:**
  - Return Period
  - Short-term quantile
  - Safety factors